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Illusory Figures Induced by Complete Figures: Individual Differences

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We investigated individual differences in the perception of three attributes, that is, illusory contour, brightness change, and depth stratification, of illusory figures induced by an incomplete figure (four pacmen) and by a complete figure (four crosses), respectively. Individual differences were mainly due to relatively lower perceptual strength of brightness change and depth stratification, especially with the complete inducing figure. With the incomplete inducing figure almost all the observers perceived all the three attributes. With the complete inducing figure, however, the illusory contour was predominant over the other two attributes, and as much as about a quarter of the observers perceived no attributes. These results suggest that the illusory figure induced by the complete figure looks quite different from that induced by the incomplete figure.

Key Words: completeness, illusory contours, Kanizsa figures

Introduction

In order to claim the criticalness and necessity for perceptual incompleteness of inducing figures in the perception of illusory figures[2], Kanizsa (1955/1987a, 1979) presented a demonstration that an illusory figure failed to be perceived in the area cornered with four crosses of perceptually complete structures. This demonstration is so convincing that Kanizsa's explanation that the formation of the illusory figure is the result of amodal completion of gaps or missing parts in the inducing figures has been widely accepted by vision researchers (e.g., Kogo, Strecha, van Gool & Wagemans, 2010).

It should be noticed, however, that Kanizsa's (1955/1987a, 1979) demonstration gave us no quantitative data on the perception of illusory figures with complete inducing figures. Quantitative studies showed that weak illusory contours or illusory figures were perceived in the area cornered or sided with complete elements (Albert, 1993; Day & Kasperczyk, 1983; Murakami, 2002; Purghé & Katsaras, 1991; Rock & Anson, 1979; Shipley & Kellman, 2003; Takiura, 2010, 2011). Later Kanizsa himself admitted the generation of illusory figures with complete inducing figures (Kanizsa, 1987b).

Illusory contours are known to have three perceptual attributes, that is, illusory contour, brightness change, and depth stratification (Kanizsa, 1979; Lesher, 1995). Takiura (2010)

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2. We restrict the term *illusory contours* to refer to the bounding contours and not to entire illusion, which we call *illusory figures*. The latter are closed region and are far more complex entities than the former (Gurnsey, Poirier, & Gascon, 1996).

found that illusory figures induced by complete figures were about 40 percent in contour clarity, were about 30 percent in enhanced brightness, and were about 20 percent in stratified depth of those induced by incomplete figures. This result strongly suggests that illusory figures induced by complete figures give observers visual impressions largely different in quality from those induced by incomplete figures. This result was, however, based on the mean data from as many as 340 observers so that it gave us no information about what illusory figures looked like to individual observer. Illusory figures induced by complete figures are so weak in perceptual strength that there may be large individual differences in percept.

In the present study we investigated what the illusory figure looked like to individual observer. Our main interest was to know how each observer perceived the attributes of the illusory figure either with the incomplete inducing figure or with the complete one. The observer was asked to depict the illusory figure induced either by the incomplete figure consisting of notched disks or by the complete figure consisting of crosses pictorially as well as in words.

Method

Observers

The observers were 220 volunteers. Post-experimental debriefing, however, revealed that 18 observers had been familiar with illusory figures previous to the experiment and thus their data were excluded. The observers whose data were analyzed ranged in age from 18 to 46 years with a mean age of 22.9 (SD = 5.5) years. None of them had previously participated in an experiment of form perception and were aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli

Stimuli were presented on a 17-inch CRT monitor at a refresh rate of 75 Hz (NANAO FlexScan E53F or NANAO FlexScan T550). The stimuli were viewed binocularly at a distance of 1 m.

The incomplete figure (Figure 1a) consisted of four notched black disks of diameter 2.0 deg. These elements were placed in order for the area cornered with them to form an imaginary square of side 3.3 deg with support ratio of 0.60. The complete figure (Figure 1b) consisted of four symmetrical black crosses whose crosspieces were 2.0 deg in length and 0.4 deg in width. The imaginary square area cornered with crosses was 3.3 deg in side so that the support ratio was 0.49. The luminance of the background was 22.1 cd/m^2 and that of the inducing figure was 3.1 cd/m^2.

Procedure

Each observer was randomly assigned to one of two groups: the incomplete figure group, and the complete figure group. Observers participated in the experiment individually in an

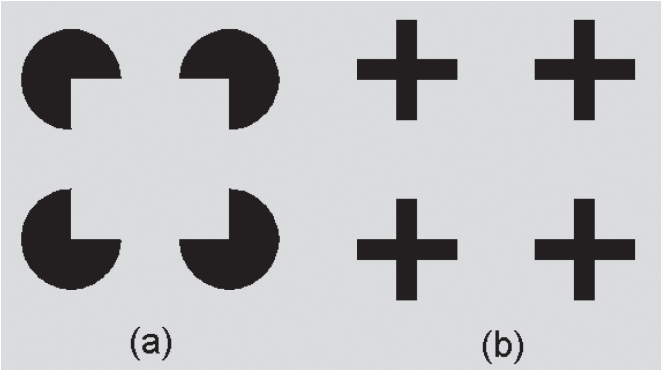

Figure 1. Inducing figures used in the present experiment: (a) the incomplete figure, (b) the complete figure.

illuminated booth.

In a pilot study we have found that not a few naive observers reported only one or two attributes if they had been given no information in advance on the attributes of illusory figures induce by incomplete figures, that is, illusory contour, brightness change, and depth stratification. It was reported that perception of the attributes could be promoted by forming observer's perceptual set (Bradley & Mates, 1985; Coren, Porac & Theodor, 1986; Rock & Anson, 1979). Illusory figures induced by complete figures were far lower in perceptual strength of attributes than that induced by incomplete figures (Takiura, 2010), so that they might be difficult to be perceived by naive observers with no knowledge of illusory figures. So we gave the observers information on the three attributes of the illusory figure to promote perception of them in advance of asking what the illusory figure tested looked like.

At the start of the experiment the observer was presented a figure consisting of three notched black disks placed in order for the area cornered with them to form an imaginary triangle. The diameter of the disk was 1.0 deg and a side of the triangle was 2.6 deg so that the support ratio was 0.38. Then he or she was given the following explanation of the attributes of the illusory figure induced by this figure:

"Look the figure carefully. One may see a triangle cornered with three black disks partially cut away. One may see sides of the triangle extending between the black figures. One may see the triangle is superimposed upon top of the black disks, with one corner over each disk. The triangle may look brighter than the surround."

After receiving the above explanation, the observer was presented either the incomplete figure or the complete one according to the group. Then the observer was asked to depict the illusion that he or she perceived pictorially on the paper printed with the stimulus figure and to give a detailed description of the illusion orally. The observer was permitted to see the stimulus freely at the experimental task.

Since the observer had been given information about the three attributes of the illusory figure prior to the experimental task, it was possible that the observer had a belief that he or she should report to the experimenter having perceived all the three attributes due to response conformity (Duval, 1976). In order to relieve the observer of the such belief, the observer was required to note that there was no correct answer to the task and that he or she should describe the illusion as it really looked like.

At the end of the experiment non-directive inquiry was made about vague part in the description of the illusory figure given by the observer to know what he or she perceived more clearly. The observer was not asked whether he or she perceived the attributes that he or she did not reported voluntarily as a matter of fact.

Results

Perceived attributes of the illusory figure

The observers' responses were classified in following eight categories according to reported attributes of the illusory figure: (1) illusory contour, brightness change, and depth stratification, (2) illusory contour and brightness change, (3) illusory contour and depth stratification, (4) brightness change and depth stratification, (5) illusory contour, (6) brightness change, (7) depth stratification, and (8) no attribute. In the present study, the observer who reported at least one attribute was regarded as having perceived the illusory figure. The observer who reported no attribute was regarded as having perceived no illusory figure.

No observer reported brightness change alone and depth stratification alone so that these two categories were not set up. Illusory boundaries and illusory lines were categorized as illusory contour. For the complete figure group, illusory strips as shown in Figure 2c were also categorized as illusory contour (see *Variety of illusory contours*).

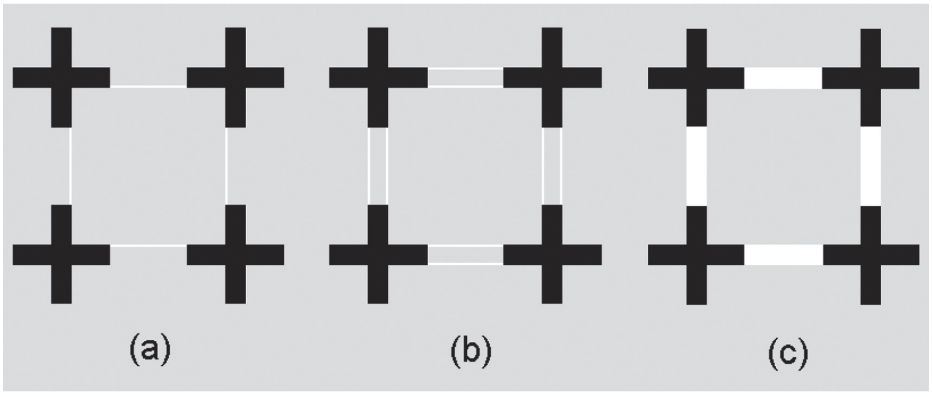

Figure 2. Illustrations of illusory lines reported by the observers in the complete figure group: (a) single lines, (b) dual lines, (c) strips.

The illusion illustrated in Figure 3, which was sometimes reported by the observers in the complete figure group, was composed of four sets of paired bright lines abutting the inducing elements. The such lines, however, were not regarded as the illusory contours comparable with those induced by the incomplete figure since they did not outline the illusory figure cornered with inducing elements. The observers who perceived the illusion illustrated in Figure 3 reported neither brightness change nor depth stratification. In the present study, they were classified in no attribute category.

Figure 3. An illustration of the illusion composed of four sets of paired bright lines abutting the inducing elements reported some observers in the complete figure group.

Table 1 shows number of the observers in each category of reported attributes in each group. Fisher's exact test revealed that the frequency distribution of observers was significantly different between categories ($p = .000$). Pairwise multiple comparisons using Holm method showed the following results ($p < .01$): Percentages of the observers who perceived all the three attributes were larger for the incomplete figure group (81 %) than for the complete figure group (5 %). Percentages of the observers who reported illusory contour and brightness change, illusory contour, and no attribute were larger for the complete figure group (15 %, 51 %, and 24 %, respectively) than for the incomplete figure group (2 %, 5 %, and 4 %, respectively). The results of multiple comparisons between categories in which as small as or less than five observers were included in each cell and other categories were not interpreted.

Categories of illusory contour and depth stratification, and of brightness change and depth stratification, respectively, included only small percentage of the observers (0-5 %) in each group.

Ninety-six percent and 76 percent of the observers reported at least one attribute in the incomplete figure group and in the complete figure group, respectively. Eighty-four percent and seven percent of the observers who perceived at least one attribute reported all the three attributes in the incomplete figure group and in the complete figure group, respectively.

Table 1 Number of observers in each category of perceived attributes of the illusory figure in each group.

Group	Illusory contour, brightness change, and depth stratification	Illusory contour and brightness change	Illusory contour and depth stratification	Brightness change and depth stratification	Illusory contour	No attribute (No illusory figure)
Incomplete Figure	83	2	5	4	5	4
Complete Figure	5	15	5	0	50	24

Variety of illusory contours

Ninety-six percent and 100 percent of the observers who perceived at least one attribute reported illusory contour in the incomplete figure group and in the complete figure group, respectively.

Illusory contour can be perceived either as a boundary between inner region and outer region of the illusory figure or as a line distinguishable from background. Naive observers in the present experiment who were unfamiliar with illusory figure phenomenon and were unacquainted with phenomenal observation of visual stimuli, however, did not seem necessarily to report on their percept with clear distinction between illusory boundary and illusory line. We can think, however, that the observer who reported the lying of a line between inducing elements perceived not an illusory boundary but an illusory line.

In the incomplete figure group, nine observers reported the polarity of illusory lines. Seven of them perceived lines brighter (or whiter) than the background and the other two darker (or grayer). One of the observers who perceived brighter lines reported the inner region of the illusory figure to be as bright as surround. The illusory figure with thin and brighter lines and with no brightness change in the area outlined with the such lines was also reported by Ronchi and Mori (1959).

In the complete figure group, three types of illusory lines were distinguished, that is, single lines, dual lines, and strips.

The single lines denote thin lines lying along the extension between facing crosspieces abutting on the central square area in the stimulus (Figure 2a). Thirty-three observers, who were 47 percent of the observers perceiving illusory lines, reported the single lines: Eight reported brighter lines, 19 darker lines, two lines with unsettled polarity, and nine lines with no reference to polarity.

The dual lines denote parallel thin lines running along the extension between both the sides of facing crosspieces (Figure 2b). Five observers, who were seven percent of the observers perceiving illusory lines, reported the dual lines: Two reported brighter lines, three darker lines.

The strips are bands on the extension between facing crosspieces (Figure 2c). We classified the illusory strips in illusory line because not only they delineated the shape of the illusory figure as the other types of illusory lines did but also they were perceptually distinguished from the background as wide lines. Thirty-two observers, who were 43 percent of the observers perceiving illusory lines, reported the strips: Seventeen reported brighter strips and 15 darker strips. Six reported that the longer sidelines looked darker than the inner area of the strips.

In the complete figure group, three observers reported single lines and the other two reported boundaries in the category of illusory contour, brightness change, and depth stratification. In illusory contour and brightness change category, four observers reported single lines, one reported dual lines, seven reported strips, and three reported boundaries. In illusory contour and depth stratification category, all the observers reported single lines. In illusory contour category, 21 observers reported single lines, four reported dual lines, and 25 reported strips. All the observers who perceived depth stratification reported single lines.

In the incomplete figure group, four observers perceived the illusory figure with brightness change and depth stratification but with no illusory contour. In the complete figure group, however, no observers perceived the illusory figure with no illusory contour.

Gray areas outside of the illusory figure were sometimes noticed. Examples of the shape of the such areas are illustrated in Figure 4. Some observers reported gradual brightening in this area with the distance from the illusory contour. In the incomplete figure group, twenty-two observers reported the gray areas. No observers who perceived no brightness change reported the gray areas. In the complete figure group, six observers who perceived single lines and one observer who perceived dual lines reported the gray areas. No observers who perceived brightness change reported the gray areas, which is inconsistent with the result in the incomplete figure group.

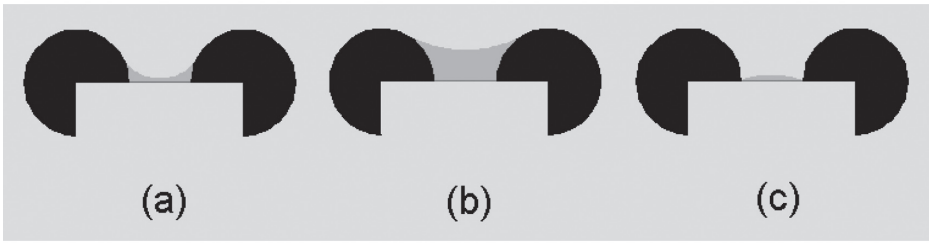

Figure 4. Illustrations of examples of gray areas outside of the illusory figure: (a) gray area limited to small space abutting the inducing elements, (b) gray area of the greater part of the space abutting the inducing elements, (c) gray area limited to narrow space not abutting on the inducing elements.

Variety of brightness change

Ninety percent and 27 percent of the observers who perceived the illusory figure reported brightness change in the incomplete figure group and in the complete figure group, respectively.

Most observers who perceived brightness change reported that the inner area of the illusory figure looked brighter than the surround. A few observers, however, reported that it looked darker than the surround. They were one in the incomplete figure group in which 89 observers perceived brighter illusory figure and three in the complete figure group in which 17 observers perceived brighter illusory figure. Halpern (1981), Takiura (2006a), and Richardson (1979) also reported that some observers perceived darker illusory figures with black inducing figures.

Twenty-two percent of the observers and no observer who perceived the illusory strips reported brightness change, and depth stratification, respectively. The lack of depth stratification was characteristic of the illusory figure with illusory strips.

Areas at and around the corners of the illusory figure sometimes looked brighter than the central area. The observers who reported the such perception were 12 and three in the incomplete figure group and in the complete figure group, respectively. In the incomplete figure group seven observers reported that areas at and around the corners of the illusory figure looked darker than the central area.

Variety of depth stratification

Ninety-two percent and 13 percent of the observers who perceived the illusory figure reported depth stratification in the incomplete figure group and in the complete figure group, respectively.

Most observers who perceived depth stratification reported that the illusory figure looked closer to them than the surround. Two observers in the incomplete figure group, however, reported that the illusory figure looked more distant from them than the surround. The such observers were also reported in Halpern (1981).

In the complete figure group, all the observers who perceived depth stratification were reported single lines or boundaries.

No attribute

Four percent and 24 percent of the observers perceived no attribute in the incomplete figure group and in the complete figure group, respectively. It is well known that naive observers do not necessarily perceive attributes of the illusory figure (Parks, 1984). In the complete figure group, nine out of 24 observers who perceived no attribute reported the such illusion as illustrated in Figure 3.

Discussion

The aim of the present study was to investigate what the illusory figure looked like to

individual observer. Our main interest was to know how each observer perceived the attributes of the illusory figure either with incomplete inducing figure or with complete inducing one.

Almost all the observers who perceived the illusory figure reported illusory contour. In the incomplete figure group, most observers also reported both brightness change and depth stratification. In the complete figure group, however, only a small number of observers reported the other attributes than illusory contour. This result shows that illusory contour is far more salient than brightness change and depth stratification and that the latter two, especially depth stratification, are often absent in the illusory figure induced by the complete figure.

Very weak depth stratification of the illusory figure induced by the complete figure will be due to the lack of occlusion cue in the stimulus. Some researchers made the claim that the occlusion cue of the inducing figure drove the formation of the illusory figure (Coren, 1972; Kogo, et. al., 2010), which cannot explain the evocation of illusory contour by the complete inducing figure with no occlusion cue. The fact that illusory contour is perceived with the complete figure supports the idea that depth stratification triggered by the occlusion cue in the inducing figure is independent of illusory contour formation (Guardini & Gamberini, 2008; Takiura, 2006b; Watanabe & Oyama, 1988).

In the incomplete figure group, gray areas outside of the illusory figure were reported only by the observers who perceived brightness change. This suggests that the gray areas were triggered to be produced by illusory brightness contrast between the illusory figure and the surround to emphasize it. In the complete figure group, however, no observers who perceived brightness change reported the gray areas. In this group the gray areas were reported by the observers who perceived single lines or dual lines, which were quite faint. So they might be triggered to be produced by these illusory lines to make their location in the display more noticeable.

No attribute was reported by only four percent of the observers in the incomplete figure group, whereas by as many as 24 percent of the observers in the complete figure group. The such large percentage of the observers who failed to perceive the illusory figure in the complete figure group may be attributable in part to the small ratio (0.20) of the width to the length of a crosspiece of the inducing cross. Purghé (1989) demonstrated that the illusory figure was weaker with small ratio (0.24) than with large ratio (0.53) of the width to the length of crosspiece of the inducing cross. Quantitative data of Day and Kasperczyk (1983) and of Takiura (2010) also suggests that the larger ratio of the length to the width of crosspiece is more favorable to illusory figure formation.

Small ratio of the width to the length of a crosspiece of the cross in the complete inducing figure in the present experiment might have also caused a variety of illusory lines, since very faint illusory lines induced by the complete figure with narrow crosspieces seem to be able to assume various appearance.

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